

- (13) R.A. $21^{\text{h}} 39^{\text{m}} 59^{\text{s}}$ Decl. $+ 52^{\circ} 37'$. Faint, partly resolved; stars 14 mag. September 16.
- (14) R.A. $22^{\text{h}} 5^{\text{m}} 21^{\text{s}}$ Decl. $+ 52^{\circ} 8'$. A remarkable cluster with six distinct radiating branches. Stars from 12 to 15. Very beautiful. September 19.
- (15) R.A. $22^{\text{h}} 11^{\text{m}} 11^{\text{s}}$ Decl. $+ 53^{\circ} 21'$. Haze round some dozen faint stars.

Description of a Perfectly Achromatic Refractor.

By H. Dennis Taylor.

Now that photography is becoming such an indispensable supplement to eye observation in astronomical work, the need for a form of refracting telescope which is perfectly corrected for photographic as well as for visual purposes becomes more and more apparent. And if, simultaneously with that condition, a great improvement in the character of the visual image can also be obtained, then we have the elements of a very substantial improvement in the refractor. In a paper which I had the honour of reading to this Society in November last I pointed out the considerable loss of light for defining purposes which must take place, owing to the usual colour aberrations ever present in the case of double object glasses made of ordinary crown and flint glasses. I there gave the losses of light, as determined by a theoretical method, for certain objectives of various sizes. Since then I have been able to carry out a delicate experiment with a $12\frac{1}{2}$ -inch object glass, whereby the amount of light lost owing to the colour aberrations was separated from the real image, and rendered approximately measurable. The result certainly confirmed the figures giving percentage of light lost, which I had previously arrived at by an *à priori* line of reasoning. I hope to have the pleasure of describing this experiment in a future paper. Thus I feel justified in saying that the principal improvement in the visual image to be expected from the almost perfect achromatism attained in this new objective is a more brilliantly defined image, the fine details being rendered in more black and white contrast than we have been accustomed to see, thus standing out, in an artistic sense, with greater sharpness. For this new objective is to all intents and purposes as achromatic as a reflecting telescope. My justification for this statement is as follows:—

It must be remembered that in practice the reflecting telescope, mirror and Huyghenian eye-piece combined, is not absolutely achromatic. However absolute may be the achromatism of the primary image, yet the eye-piece, if of the Huyghenian or Ramsden type, always introduces its own colour aberrations. Taking the case of a Huyghenian eye-piece of 1 inch equivalent

focal length, the virtual longitudinal colour aberration from B to H γ (G') which it would introduce would amount to about three-hundredths of an inch. This amount in the case of a reflector of a focal length equal to seven and a half times its aperture is about equal, as regards detriment to vision, to a longitudinal colour aberration of six-hundredths of an inch in the case of either a reflector or a refractor of a focal length equal to fifteen times its aperture. I shall shortly point out that in the case of even an objective of 2 feet aperture, and of 36 feet focal length, of the new construction, the residual longitudinal colour aberrations need not be expected to amount to as much as six-hundredths of an inch; while at the same time an achromatic single lens eye-piece may be employed, presenting no spectrum and having only two reflecting surfaces. Or, supposing a 1-inch Huyghenian eye-piece to be generally employed on such a telescope, the objective may be sufficiently over-corrected to counteract the longitudinal colour aberrations of that eye-piece.

The problem of devising a perfectly achromatic objectglass has occupied the attention of many scientific men and opticians for a considerable time. The Rev. Vernon Harcourt spent twenty-five years or so of his life in melting and trying new forms of glass with a view to producing two glasses of similar rationality. But none of his experiments resulted in practical success. The problem has also deeply occupied the attention of Sir G. G. Stokes and the late Professor Pritchard. In short, it is a problem which has exerted a great fascination over many minds. Some, notably Professor Hastings in America, and Professor Abbe of Jena, fully realised that 'practical success need not by any means depend upon the employment of only two lenses in the objective. Professor Hastings published an article in the *American Journal of Science and Art* (for December 1879) in which he gave the results of calculations of several forms of objectives made of three kinds of glass, in some of which a remarkably near approach to perfect achromatism seemed to be possible. However, none of these combinations seem to have been worked into practical shape, and, so far as I know, principally because one or other of the glasses employed—all, I believe, the production of Mons. Feil of Paris—could not be made hard enough or durable enough for practical use.

In 1884 the justly celebrated firm of Herren Schott und Ges started their optical glass manufactory at Jena for the principal purpose of making both old and new varieties of optical glass on a commercial scale, at the same time addressing themselves in a most thorough and scientific manner to the problem of producing two glasses whose rationality of dispersion should be identical, at the same time that the difference between their dispersive powers should be sufficient to enable a perfectly achromatic double object glass to be constructed, without having to resort to impracticably deep curves.

But in spite of the skill and scientific method brought to bear upon this problem, and exhaustive trials of all known substances capable of being fused into glasses, it cannot be said that that aim has been realised; and I really believe that a practicable *double* object glass, even reasonably free from secondary colour aberration, is as far from being realised as it was ten years ago. For it should be borne in mind, when aiming at an object glass of two glasses which shall be perfectly achromatic, that although it may be possible to considerably reduce the discordance between their respective rationalities of dispersion, yet the reduction of secondary spectrum at the focus accruing from that improvement may be largely counteracted or even wholly neutralised by the deeper curvatures or higher powers of the two component lenses, which are rendered necessary by that smaller difference of dispersive powers of the two glasses which has hitherto inevitably accompanied the closer agreement in rationality of dispersion. In short, whether using two or three lenses, the deeper the curves, or the more powerful the component lenses, required for obtaining a given focal length, the more close and strict must be the concordance of rationality of dispersion between the glass (or two glasses combined) forming the positive element and the glass forming the negative element of the objective. To be sure, certain double combinations have been made in which the secondary spectrum has been reduced to about half the usual amount. For instance, Dr. Czapski of Jena* describes a form of objective of which two or three were made by Bamberg of Berlin, and also, I believe, by Dr. Czapski himself, in which the positive lens was made of Schott's dense barium phosphate crown S·30, and the negative lens of Schott's borate flint S·8 or S·7. This is somewhat similar to a combination of the same flint with a nearly similar crown which was carried out by Messrs. Cooke about seven years ago, and found to make a more than usually achromatic object glass. But the borate flints are too soft for practical purposes, and, moreover, Dr. Schott has informed us that it is almost impossible to get good discs of this glass of over 5 inches aperture.

A few years ago Professor Hastings patented in America another form of double object glass in which the secondary spectrum was reduced to about half. For his positive lens he made use of potassium silicate crown (Schott's 0·13), and for his negative lens Schott's boro-silicate flint glass 0·161. This combination turned out to be impracticable: the crown is too hygroscopic, and the flint, Dr. Schott has informed us, cannot be made good enough.

Having considered all the facts of the case, I was inevitably

* In Dr. Czapski's work, *Theorie der optischen Instrumenten (nach Abbe)*, on page 131, will be found graphic diagrams showing the somewhat reduced amounts of secondary spectrum exhibited by these combinations as compared with that exhibited by an ordinary object glass of crown and dense flint.

led, as a few other inquirers have been led, to the conclusion that there was little prospect of making an object glass of two lenses whose achromatism would be so much superior to that of the ordinary objective as to fully compensate for the other practical disadvantages which would ensue, either in the shape of curves difficult to work or a confined field of view, not to mention several other serious drawbacks.

Some two years ago I entered into an investigation as to the possibility of producing a triple object glass, free from secondary spectrum, whose curves should be such as to permit of all the other necessary or desirable optical qualities and certain practical advantages being attained. After a very searching and prolonged trial of all the likely combinations of glasses picked out of the numerous new and old types of glass, put at the disposal of the optical world by the genius of Dr. Schott and Professor Abbe, and by help of every opportunity for investigation and experiment afforded me in the workshops of Messrs. Cooke, I at last realised a triple combination of three different sorts of glass, which, while yielding a degree of achromatism almost greater than anything which I had at first ventured to hope for, at the same time rendered possible the achievement of certain other important optical qualities and practical conveniences which yet remain to be specified.

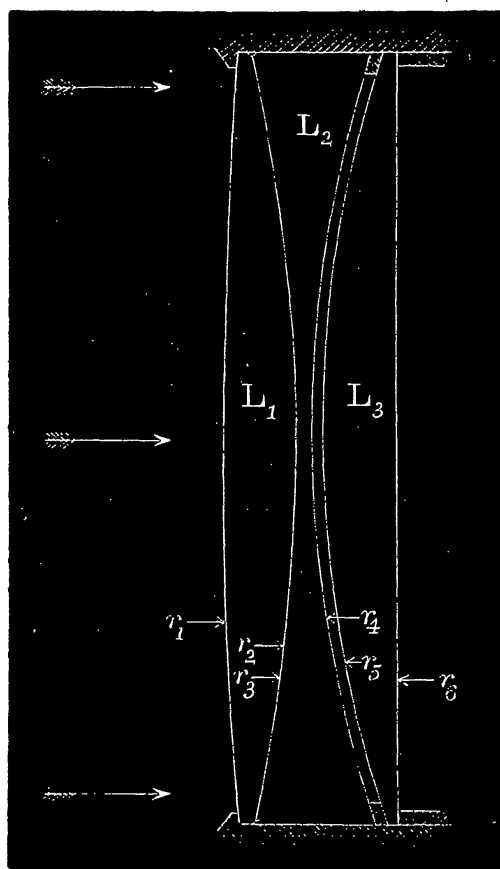
Taking the optical qualities first—

1. This objective can be made free from spherical aberration for all colours simultaneously. This is of the utmost importance in the case of an objective having any pretensions to perfect achromatism. In a double objective of ordinary construction having a double concave or concavo-plane flint lens, it is well known that when the brightest yellow green rays are perfectly corrected for spherical aberration, then the red rays are under-corrected, and the blue rays are over-corrected for spherical aberration; a condition of things, however, which escapes notice in the presence of the greater fault of the secondary spectrum.

2. The objective is so arranged as to give the largest possible field of good definition. The image of a star formed at, say, 2° from the optic axis is free from coma or side flare, and also from colour. If a star is focussed into the centre of the eye-piece and the objective is tilted, even very considerably, then the image of the star remains symmetrical and without side flare, and only showing the inevitable astigmatism. This condition is of the utmost importance in the case of an objective when used for photographing celestial objects having considerable angular extension, or for transit instruments which are generally provided with eye-pieces having a certain amount of lateral travel.

3. The curves are also such that a ray parallel to the optic axis traced through the margin of the objective enters and leaves the flint lens at approximately equal angles. This is of con-

siderable importance in the case of deep curves, and especially in large-sized objectives, because the flint lens is by a long way the weakest, in a mechanical sense, of the three lenses, and therefore most liable to flexure across its diameter, and such flexure would in the large sizes, and under ordinary circumstances, give rise to considerable aberrations of the marginal rays from true focus. But if refraction of such marginal rays takes place about *equally* at both surfaces, then the optical results of such flexure or sagging of this lens are reduced to practically nothing. The action of the edge of the flint lens upon the marginal rays is in this case the same as that of a prism when set at minimum deviation, which may be rotated through a relatively considerable angle without bringing about a very perceptible increase in deviation.



The accompanying diagram is a section of the objective taken along a diameter. The focal length is eighteen times the aperture. If specially required, the aperture can be made equal to one-fifteenth of the focal length in the case of sizes up to 8 or 10 inches aperture. A relatively large focal length is, however, most to be recommended.

The lens L_1 which is placed first to receive the parallel rays

is made of Schott's baryta light flint glass 0.543, whose refractive index for D ray is about 1.564.

The negative lens L_2 is made of Schott's new boro-silicate flint glass, which is a variety of their 0.164. Its refractive index for D is 1.547.

The glass of which the third lens L_3 is made is a sort of light silicate crown (Schott's 0.374), which differs from ordinary hard crown in having a lower dispersive power and a somewhat different rationality. Its index of refraction for D is about 1.511.

The separation between the negative lens L_2 and the positive lens L_3 is designed for the purpose of correcting the spherical aberration perfectly for all colours.

The contiguous second and third surfaces r_2 and r_3 are curved to exactly the same radius; also the fourth and fifth surfaces r_4 and r_5 are curved to the same radius. The last surface r_6 is concave, and curved to a radius equal to nearly twice the focal length. There are thus three hollow surfaces whose figuring can be directly tested by reflected light, while each of the other three convex surfaces can be tested for figuring in an indirect manner. For instance, if all three concave surfaces are approved, and faults at the focus are found to exist which must be caused by defective figuring in one or more of the convex surfaces, then they can be tested in the following manner:—

If the faults at the focus are due to defective figuring in the second surface, those faults will more or less totally disappear on introducing some liquid having a refractive index approximately equal to that of glass between the two surfaces r_2 and r_3 . If it is desired to test the fifth surface, then the brass ring separating L_2 from L_3 is taken out and put between the second and third surfaces, while L_2 and L_3 are brought close together. The objective being first tested in this state with its surfaces dry and the faults at the focus noted, then the refracting liquid may be introduced between the fourth and fifth surfaces, when, if the fifth surface is faulty in figure, the faults at the focus will more or less disappear. But if both the second and fifth surfaces are not found to be faulty by this method, then the conclusion is that the first surface r_1 is really at fault. Thus, all surfaces may be easily tested either directly or indirectly, and the whereabouts of small errors of figuring revealed, which are too fine to be appreciated by the use of spherometers or other mechanical tests. Thus no time need be lost in refiguring the wrong surfaces.

The baryta light flint and light silicate crown glasses used for the two exterior lenses are as hard and durable as ordinary crown glass, and if anything more colourless and transparent.

The boro-silicate flint glass used for the negative lens is of quite a different type from that used by Professor Hastings for his patented doublet. Indeed, this flint is the only available

B B

glass which can be used for apochromatic objectives, and can be turned out in large-sized discs. Its mechanical hardness is very great—greater indeed than that of hard crown. It is beautifully transparent to all the brighter rays of the spectrum, but begins to absorb the violet rays after the G line is passed. This characteristic imparts a lemon yellow colour to a lens when of two inches thick or over, but it is scarcely noticeable in the case of lenses of moderate sizes.

In a town atmosphere, where sulphuretted hydrogen or sulphuric acid abounds, it would not be safe to use this flint for an exterior lens; but when enclosed between the two positive lenses, as in this objective, we have no reason for expecting it to be any less permanent in its polish than the dense flint glass which has hitherto been used for double object glasses of the usual construction. Or even supposing a slight amount of tarnishing of its surfaces did take place after many years, as is the case with the flint glasses hitherto used for telescope object glasses and prisms, it may yet be asked whether the transparency or light-transmitting power of the objective would be in any degree impaired. We know well enough that a tarnished optical surface does not look so brilliant *by reflected light*. It may seem a somewhat startling statement to make, but nevertheless it is a fact, that certain flint glasses which we have experimented with by local tarnishing have been found to transmit actually more light where tarnished than where the surfaces had had their original polish preserved, and in no case has it ever been found that tarnish in any perceptible degree interfered with transparency.* We have yet to make some further experiments in this direction, and I hope at some future time to throw the proofs of this statement on the screen for your inspection. Those who use ordinary refractors may congratulate themselves on the fact that the light-gathering power of their objectives slightly increases with age, provided the surfaces are kept clean. However, leaving that interesting point for the present, I may say that enough experiments, extending over about a year and a half, have been made with this new glass to fully satisfy Messrs. T. Cooke & Sons of its lasting properties, and to warrant them in guaranteeing the permanency of this objective.

I will here give a table setting forth the optical properties of the three glasses, and also showing how very closely all the rays of the spectrum can be refracted to one focus.

* Of course this statement is not intended to apply to the case of a surface which is actually corroded, so as to appear at all *grey* or *milky* by reflected light.

1	2	3	4	5	6
Region of Spectrum.	Partial Dispersions or $\Delta\mu_1$ for Glass 0.543.	Partial Dispersions or $\Delta\mu_3$ for Glass 0.374.	Combined Partial Dispersions or $\Delta\mu_1 + \Delta\mu_3$ for Glasses 0.543 and 0.374.	Proportional Dispersions C to F being Unity for Glasses 0.543 + 0.374.	Proportional Dispersions for Boro-silicate Flint 0.658.
C to F	0.1115	0.0844	0.1959	1.0000	1.0000
...	(1.0000)	(1.0000)			
A to C	0.0374	0.0296	0.0670	0.3420	0.3425
...	(0.3354)	(0.3507)			
D to F	0.0790	0.0593	0.1383	0.7059	0.7052
...	(0.7085)	(0.7026)			
E to F*	0.0369	0.0274	0.0643	0.3282	0.3278
...	(0.3309)	(0.3247)			
F to G (H γ)	0.0650	0.0479	0.1129	0.5763	0.5767
...	(0.5830)	(0.5675)			
F to H $_1$ *	0.1322	0.0976	0.2298	1.1730	1.1745
...	(1.1857)	(1.1564)			

This table is calculated on the supposition that

$$\frac{1}{\rho_1} = \frac{1}{\rho_3},$$

where $\frac{1}{\rho_1}$ = the sum of the reciprocals of the radii of the first

lens and $\frac{1}{\rho_3}$ = the sum of the reciprocals of the radii of the third

lens. This pretty well represents an average case, and with the present meltings of glass gives the most perfect colour correction. The curves may of course be varied within certain limits in order to compensate for variations in the optical qualities of the glasses.

But under the conditions above defined it is evident to those conversant with optics that the partial dispersions for these two positive lenses combined, for any given region of the spectrum, is obtained by simply adding together their respective dispersions for that region of the spectrum.

In column 2 are given the partial dispersions of baryta light flint glass 0.543 for the different regions of the spectrum indicated in column 1.

In column 3 are given the corresponding partial dispersions for the light silicate crown glass 0.374. The figures in brackets beneath these in columns 2 and 3 indicate the relative partial dispersions for each region of the spectrum when the dispersion from C to F for each glass is taken as unity.

* Figures relating to spectral regions E to F and F to H $_1$ are calculated from Messrs. Schott's measurements by means of Cauchy's dispersion formula.

In column 4 are given the sums of the partial dispersions for each region of the spectrum, obtained by simply adding together the partial dispersions for 0.543 and 0.374 respectively for each region of the spectrum indicated in column 1.

In column 5 the combined dispersion for the two positive lenses for the region C to F is taken as unity, and the relative proportions of the combined dispersions for the other regions of the spectrum are expressed in fractional parts of the combined dispersion from C to F. Finally, in column 6 are given the corresponding proportional dispersions in the same sense as in column 5 for the boro-silicate flint glass 0.658. I need scarcely explain that the perfection of the achromatism of the triple combination is made manifest by the remarkably close agreement between the proportional dispersions for the two positive lenses combined, on the one hand, and the proportional dispersions for the negative lens on the other hand.

The rationality of dispersion, as it is generally termed, is in remarkably close agreement.

These figures do not pretend to accuracy in the fourth decimal place, but I would point out that an error of .0010 in any one of these figures would, in the case of a 6-inch O.G. of 108 inches focal length, correspond to a longitudinal aberration of only .02 inch; an amount which, I believe, the most delicate test could scarcely reveal, owing to the cone of rays close to focus merging in such a remarkable manner into the cylindrical form.

Owing to the expensive nature of experiments of this sort, the first objectives actually made on this principle and finished were of the moderate aperture of $3\frac{1}{2}$ inches; but these were found so successful as to leave no doubt about much larger sizes being practicable should the glass be forthcoming. However, a recent visit to Dr. Schott and Professor Abbe at Jena has quite set at rest any doubts as to the possibility of turning out discs of considerable sizes, many discs of moderate dimensions, up to 9 inches, and possibly 12 inches diameter, being already available. Dr. Schott is of opinion that only actual experience with future meltings will determine up to what sizes it will be possible to manufacture perfect discs.

It is easily seen from the diagram that the total thickness of glass in this new objective is a trifle over $1\frac{1}{2}$ times the thickness of glass used in an ordinary double objective of the same aperture, and it might be thought that a serious loss of light might result therefrom in large sizes. I have recently made some experiments upon the transparency of some blocks from 4 to 5 inches thick of the three glasses used in the objective, and have been pleased to find that a thickness of 5 inches of the baryta light flint absorbed only 40 per cent. of candle light; a thickness of $4\frac{7}{8}$ inches of boro-silicate flint absorbed 27 per cent. of candle light (though doubtless more of daylight); while a

thickness of $5\frac{1}{8}$ inches of the light silicate crown absorbs only 20 per cent. of candle light.

These figures must be regarded as preliminary. I intend to check the results and present them in a more accurate and digested form on a future occasion. But as far as they go these results are surprising as showing what an improvement has taken place in the transparency of glasses (a few blocks of ordinary crown and flint glasses were also tried and found nearly as transparent as the block of 0.374) within the last few years, when thicknesses of four inches only were generally found to absorb as much as one half of the light.

Thus this triple objective might be made in very large sizes, 2 feet aperture or so, before the loss of light due to thickness would become so great as to put it on an equality as regards light-gathering power with a Newtonian reflector of average condition and similar aperture.

Buckingham Works, York.

Brilliant Detonating Fireball of 1894 January 25.

By W. F. Denning.

A very murky condition of sky, with occasional rain, appears to have prevailed over a considerable part of England on the night of 1894 January 25, and the only celestial objects visible were *Jupiter* and two or three of the brighter stars shining very dimly through the clouds. At about 10^h 1^m, in the Midland Counties, the dark atmosphere was instantaneously illuminated with a light perfectly dazzling in its intensity, and people who noticed it thought for a moment that the full Moon had suddenly come into view. On glancing upwards, however, they immediately detected the real cause in the form of a large pear-shaped fireball rolling across the sky from the direction (as observed at many places) of N.W. to S.E., and scattering behind it a bright tail of sparks. Those who obtained the most complete view of the object describe it as small at first, like an ordinary shooting star, but, after traversing about one-third of its course, it appears to have suddenly burst out into a startling size and brightness, and afterwards divided into two parts. As it disappeared the section of its track following the nucleus was beaded with fragments decreasing in size from the foremost. The colour of the latter was variously described as blue and green, and several observers compare it with the electric light; the tail and hinder parts of the nucleus appear to have been yellow merging into red. From one to four minutes after the meteor had disappeared alarming detonations were heard at Worcester, Droitwich, Birmingham, Alvechurch, Malvern, Ross, Stroud, Cheltenham, and numerous other places in the same